

****FULL TITLE****

*ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION***

****NAMES OF EDITORS****

Cosmological Parameters 2006

Ariel G. Sánchez¹, and Carlton M. Baugh²

Abstract. Recent measurements of the cosmic microwave background radiation (CMB), particularly when combined with other datasets, have revolutionised our knowledge of the values of the basic cosmological parameters. Here we summarize the state of play at the end of 2006, focusing on the combination of CMB measurements with the power spectrum of galaxy clustering. We compare the constraints derived from the extant CMB data circa 2005 and the final 2dFGRS galaxy power spectrum, with the results obtained when the WMAP 1-year data is replaced by the 3-year measurements (hereafter WMAP1 and WMAP3). Remarkably, the picture has changed relatively little with the arrival of WMAP3, though some aspects have been brought into much sharper focus. One notable example of this is the index of primordial scalar fluctuations, n_s . Prior to WMAP3, Sánchez et al. (2006) found that the scale invariant value of $n_s = 1$ was excluded at the 95% level. With WMAP3, this becomes a 3σ result, with implications for models of inflation. We find some disagreement between the constraints on certain parameters when the 2dFGRS $P(k)$ is replaced by the SDSS measurement. This suggests that more work is needed to understand the relation between the clustering of different types of galaxies and the linear perturbation theory prediction for the power spectrum of matter fluctuations.

1. Introduction

In the last decade, the measurements of fluctuations in the temperature of the cosmic microwave background radiation (CMB) have shown a dramatic improvement marking the start of a new, data-rich era in cosmology (de Bernardis et al. 2000).

The CMB power spectrum encodes information about the values of the cosmological parameters. However, degeneracies exist between certain combinations of parameters which impose a limit on the precision attainable using CMB data alone. In order to break these degeneracies it is necessary to combine the CMB data with other datasets, such as the power spectrum of galaxy clustering. The two-degree field galaxy redshift survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS) are the largest redshift surveys available and give the most detailed description of the large scale structure of the Universe (LSS) as traced by galaxies. A consistency check between these two datasets would test the hypothesis about the relation between the galaxy power spectrum and the linear perturbation theory prediction for the power spectrum of matter fluctuations.

¹Instituto de Astronomía Teórica y Experimental (IATE), OAC, UNC, Laprida 854, X5000BGR, Córdoba, Argentina.

²The Institute for Computational Cosmology, Department of Physics, University of Durham, South Road, Durham DH1 3LE, UK.

The constraints quoted in this work were obtained by Sánchez et al. (2006; hereafter S06). In Section 2, we describe the data used in the parameter estimation. In Section 3, we summarize the main results of S06 for the parameter constraints and perform a comparison with those obtained by Spergel et al. (2006). We also compare the results obtained using the 2dFGRS and SDSS galaxy power spectra. Finally, we summarize our conclusions in Section 4.

2. The Method

In order to constrain cosmological parameters, S06 used a compilation of recent measurements of the CMB, including the WMAP first year data (WMAP1; Hinshaw et al. 2003; Kogut et al. 2003), extended to smaller angular scales with information from ACBAR (Kuo et al. 2004), VSA (Dickinson et al. 2004) and CBI (Readhead et al. 2004). These datasets were combined with the power spectrum of galaxy clustering measured from the final 2dFGRS catalogue by Cole et al. (2005). In order to model the effects of non-linearities and galaxy bias, S06 followed the scheme developed by Cole et al. who applied a correction to the shape of $P(k)$ of the form

$$P_{\text{gal}}(k) = b^2 \frac{1 + Qk^2}{1 + Ak} P_{\text{lin}}(k), \quad (1)$$

where $A = 1.4$ and $Q = 4.6$ are the preferred values for the 2dFGRS and b is a constant bias factor. The power spectrum data was used for $0.02 \, h\text{Mpc}^{-1} < k < 0.15 \, h\text{Mpc}^{-1}$.

S06 analysed a range of parameter sets and priors, allowing for massive neutrinos, curvature, tensors and general dark energy models. Here we focus on the ‘basic-six’ parameter space, defined by

$$\mathbf{P}^{\text{b6}} \equiv (\omega_{\text{dm}}, \omega_{\text{b}}, \tau, n_{\text{s}}, A_{\text{s}}, \Theta), \quad (2)$$

from which other parameters can be derived.

3. Results

When the parameter space defined by (2) is explored using CMB data alone, the results show a degeneracy that involves all six parameters and which is seen most clearly in τ , n_{s} and A_{s} . The 2dFGRS $P(k)$ helps to break this degeneracy, particularly by tightening the constraints on w_{dm} : ($w_{\text{dm}} = 0.105^{+0.013}_{-0.013}$ for CMB data alone and $w_{\text{dm}} = 0.1051^{+0.0046}_{-0.0047}$ for CMB plus 2dFGRS). When the CMB data is combined with the 2dFGRS $P(k)$, the recovered value of the spectral index of scalar perturbations is $n_{\text{s}} = 0.954^{+0.023}_{-0.023}$ with $n_{\text{s}} < 1$ at the 95% confidence level, a deviation from scale invariance ($n_{\text{s}} = 1$). This result has strong implications for the inflationary paradigm.

Table 1 shows a comparison of the constraints on the basic-six parameter set obtained by S06 with those obtained by Spergel et al. (2006) using information from the third year of flight of WMAP. The new WMAP data represent a significant improvement over WMAP1 due to the longer integration time and

Table 1. Comparison of the constraints on the basic six parameter set defined by (2) from Sánchez et al. (2006) and Spergel et al. (2006)

Parameter	Sánchez et al. (2006)	Spergel et al. (2006)	
	WMAP1(ext.)+2dFGRS	WMAP3 only	WMAP3+2dFGRS
ω_b	0.0225 ± 0.0010	0.0223 ± 0.0008	0.0222 ± 0.0007
ω_m	0.127 ± 0.005	0.126 ± 0.009	0.1262 ± 0.0048
h	0.735 ± 0.022	0.74 ± 0.03	0.732 ± 0.021
τ	0.118 ± 0.060	0.093 ± 0.029	0.083 ± 0.029
n_s	0.954 ± 0.023	0.961 ± 0.017	0.948 ± 0.016
σ_8	0.773 ± 0.053	0.76 ± 0.05	0.737 ± 0.039
Ω_m	0.237 ± 0.020	0.234 ± 0.035	0.236 ± 0.020

a better understanding of systematic effects. The new polarization data is particularly helpful in constraining τ , breaking some of the degeneracies present in the temperature data. The two sets of constraints are in remarkable agreement. In particular, the new results confirm, with a higher statistical significance, the detection by S06 of a deviation from scale invariance.

The marginalized constraints obtained for the CMB plus 2dFGRS $P(k)$ case are in striking agreement with those in the CMB only case, showing the impressive consistency between these datasets. There is a clear discrepancy, however, with the results obtained using CMB data plus the SDSS $P(k)$ estimated by Tegmark et al. (2004). This difference can be traced back to the density of dark matter, with the SDSS data pointing to higher values of ω_{dm} .

On considering the basic-six parameter space extended by the incorporation of the dark energy equation of state parameter, w_{DE} , we find $w_{DE} = -0.45^{+0.23}_{-0.23}$ using the SDSS $P(k)$, which is much higher than the value $w_{DE} = -0.85^{+0.18}_{-0.17}$ obtained in the case of the 2dFGRS $P(k)$ and inconsistent with a cosmological constant. Again, this discrepancy is due to the preferred values of ω_{dm} . Fig. 1 shows the degeneracy in the $\Omega_m - w_{DE}$ plane for CMB data alone. Adding information from the galaxy power spectrum breaks this degeneracy. If the galaxy $P(k)$ data prefer a high value of Ω_m , as is the case for the SDSS data, then a high value of w_{DE} will result.

4. Conclusions

We have reviewed the constraints on the values of the basic cosmological parameters obtained using a combination of CMB data and the galaxy power spectrum of the final 2dFGRS. The data shows clear evidence for a departure from a scale invariant primordial spectrum of scalar fluctuations; the value $n_s = 1$ is formally excluded at the 95% confidence level.

A comparison with the results from Spergel et al. (2006) obtained using the data from the third year of flight of the WMAP satellite shows an excellent agreement, which is a reassuring validation of the cosmological paradigm. In

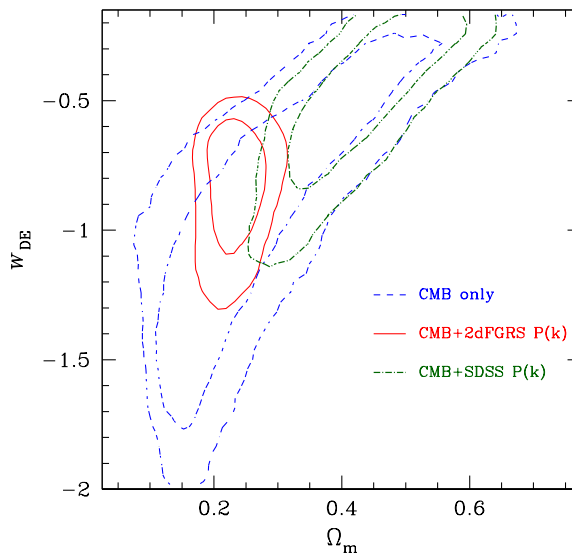


Figure 1. The marginalized posterior likelihood in the $\Omega_m - w_{DE}$ plane for the basic six plus w_{DE} parameter set. The lines show the 68% and 95% contours obtained in the CMB only (dashed), CMB+2dFGRS $P(k)$ (solid) and the CMB+SDSS $P(k)$ (dot-dashed) cases.

particular, the new results confirm the detection by S06 of a deviation from scale invariance with a higher statistical significance.

There is an impressive agreement between the results obtained for CMB data alone and for CMB data plus the 2dFGRS power spectrum data. However, there is some tension between the constraints from the CMB and SDSS datasets. Cole, Sánchez and Wilkins (2006) have shown that these differences are due to the r -band selected SDSS catalogue being dominated by more strongly clustered red galaxies, which have a stronger scale dependent bias. It is therefore important to accurately model the distortion in the shape of the power spectrum caused by nonlinearity and scale dependent bias in order to obtain unbiased constraints on cosmological parameters from present and future galaxy surveys.

References

- de Bernardis P., et al., 2000, *Nature*, 404, 955
- Cole S., et al. 2005, *MNRAS*, 362, 505
- Cole S., Sánchez A.G., Wilkins S., 2006, astro-ph/0611178
- Dickinson C., et al. , 2004, *MNRAS*, 353, 732
- Hinshaw G., et al., 2006, *ApJS* submitted, astro-ph/0603451
- Kogut A., et al., 2003, *ApJS*, 148, 161
- Kuo C.L., et al., 2004, *ApJ*, 600, 32
- Readhead A.C.S. et al., 2004, *ApJ*, 609, 498
- Sánchez, A.G., et al 2006, *MNRAS*, 366, 189
- Spergel D.N., et al., 2006, *ApJS* submitted, astro-ph/0603449
- Tegmark M. et al., 2004, *ApJ* 606, 702